

From decaying to conveying:

BIOMETHANE FROM WASTES CAN FUEL OUR SHIPS WHILE
SLASHING EMISSIONS.

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Alexander MacFarlane, RNG Connect, October 2025

Introduction:

Robust, fair and transparent avoided emissions accounting will enable open lagoons, dumps and burning fields worldwide to be wrestled into distributed industrial ecosystems providing clean fuel for ships, trucks, chemicals manufacturing and industry worldwide. Unfortunately, regulatory frameworks recognizing the emissions avoidance of feedstock acquisition can be complex and controversial. The analyses in this series provide supporting information, working examples and rationale to bolster avoided emissions and negative carbon intensity biomethane life cycle accounting.

Problem statement:

Biogenic waste materials are highly preferred as new sources of biofuels, as they do not compete with food or feed, nor contribute to deforestation.^{1,2} Un-managed, or under-managed biogenic wastes also represent a large and growing climate risk due to fugitive nitrous oxide and methane released by their uncontrolled decomposition (decaying).³ Utilizing biogenic wastes to produce biomethane through industrial scale anaerobic digesters will displace the use of fossil fuels while capturing important fugitive emissions.⁴ However, current regulatory efforts such as the International Maritime Organization's Net Zero Framework (IMONZF) risk building on Euro-centric Life Cycle Assessments (LCA) that do not recognize avoided emissions associated with biowaste and ag residue-generated biomethane (livestock manure will likely be credited).⁵ Developing and emerging economies facing waste management challenges will especially benefit from full avoided emissions accounting. Crucial waste feedstocks will be under-exploited should schemes such as IMONZF fail to accredit avoided emissions associated with biowastes. Or, as the International Energy Agency (IEA) puts it: "The competitiveness of biogases can be improved if a value is attached to the positive externalities arising from their use."⁶ Further, counterproductive environmental harm becomes more likely if up/downstream fugitive emissions are not monetized and tracked assiduously. The latest low-carbon frameworks, especially Canada's Clean Fuel Regulation (CFR), successfully accredit carbon negative biomethane with simple and transparent elegance while complying with IPCC carbon accounting principles.

¹ (European Commission Joint Research Centre (JRC) 2024a)

² (European Environment Agency (EEA) 2020)

³ (United Nations Environment Programme (UNEP) & Climate and Coalition 2021)

⁴ (European Commission Joint Research Centre (JRC) 2024b)

⁵ EU's RED II appears to provide the biofuels LCA backbone for IMONZF, which does include an avoided emissions bonus for manure-based biomethane but does not recognize the avoided emissions of biomethane from biowaste or agricultural residue. Projects based on these feedstocks can only achieve negative carbon intensity if the projects deploy carbon sequestration or carbon recycling. (Sustainable Biomass Program (SBP) 2022)

⁶ International Energy Agency (IEA) (2022)

Brief #	Release Date	Title
1	10/29/2025	<i>How big is the opportunity? The Business-as-Usual emissions impact of biomethane feedstocks.</i>

Objective This analysis quantifies fugitive GHG emissions associated with the acquisition of waste feedstocks for biomethane production in addition to fossil carbon displacement by the resulting biomethane product. The business-as-usual (BAU) management of organic wastes (aka the “counterfactual” or “reference” scenario) results in massive releases of super-polluting GHGs, and deployment of anaerobic digestion brings these wastes into a managed, controlled, monitored and *monetized* process with numerous external benefits. Displacement of synthetic fertilizers, soil carbon sequestration, and utilization of biogenic CO₂ are among the downstream *additional* emissions reductions enabled by this feedstock acquisition and treatment. But the diversion of wastes from BAU and the resulting avoided emissions is perhaps the most valuable benefit of anaerobic digestion in our carbon-constrained atmosphere. Overall estimates of the effectiveness of methane destruction or avoidance of nitrous oxide emissions enabled by anaerobic digestion are not included. Digester systems purpose-built for whole system emissions management could outperform the current typical destruction rates (90% for methane, 30-50% for nitrous oxide in the manure management context⁷).

Included:

- Gross non-CO₂ GHG totals available for capture via feedstock acquisition into anaerobic digestion.
- Avoided fossil gas CO₂ emissions resulting from the product biomethane.

Excluded:

- Capture *effectiveness* of the biomethane pathway.
- All processing and downstream fuel pathway carbon additive factors such as leakage, parasitic energy consumption, transport, compression, conversion or combustion slip-by.
- Woody residual to biomethane via gasification.
- Black carbon from crop burning. (400M dry tons are burned worldwide annually! ⁸)
- Soil carbon sequestration and fossil-derived fertilizer displacement, CO₂ utilization.

Method The study aligns International Energy Agency (IEA) estimates of global biomethane potential with the emissions associated with business-as-usual feedstock management. (IEA numbers and groupings minimally modified as noted.) Biogenic CO₂ released by the combustion of biomethane is assumed to have zero GWP, in line with worldwide scientific convention, while fossil gas is assumed to have a carbon intensity of 56.1 gCO₂e/MJ net energy (LHV) on combustion⁹. Biomethane is assumed to displace fossil gas 1:1 on an energy basis, so displacement of fossil CO₂ by biogenic CO₂ is akin to biomethane energy potential. Woody waste biomethane potential was not included.¹⁰

⁷ (Leip et al, 2010)

⁸ (<https://www.fao.org/faostat/en/#data/GCE>)

⁹ (IPCC 2006)

¹⁰ (International Energy Agency (IEA) 2022)

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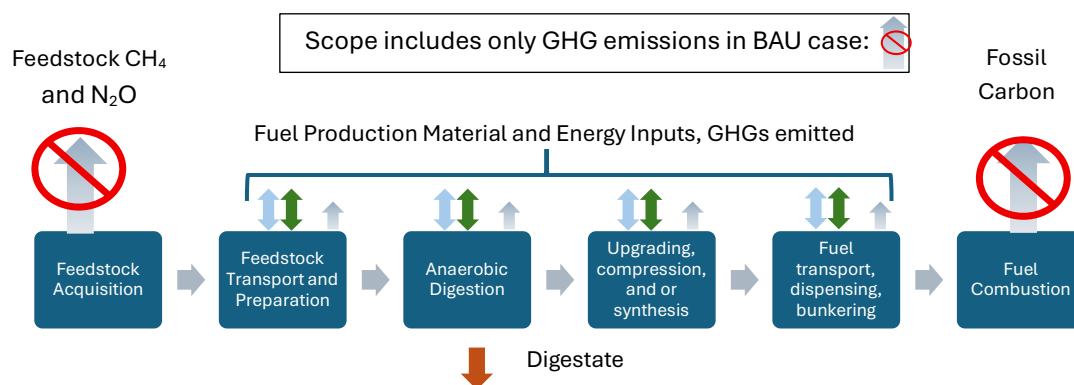
The three main AD feedstock categories from the IEA estimate; biowaste, crop/ag residue, and manure were aligned with the following emissions categories:

Biowaste: CH₄ from Solid waste disposal (including landfills and open dumping), CH₄ and N₂O from Biological treatment of solids waste, CH₄ from Incineration and Open Burning of Waste, CH₄ and N₂O from Wastewater treatment and discharge. IPCC Emissions Categories 4A, 4B, 4C and 4D, respectively. All from EDGAR v7.¹¹

Ag Residue: CH₄ and N₂O from burning of crop residue, N₂O from crop residue left on the fields. FAO emissions from crops, Dataset GCE, element codes 72257,72302 and 72307.¹²

Manure: CH₄ and N₂O Direct from Manure Management and N₂O from manure applied to fields. FAO emissions from livestock, Dataset GLE, element codes 72256,72301 and 72306.¹³

Other externalities could be included such as the emissions associated with displaced synthetic fertilizer, recycling of biogas CO₂, or soil carbon accumulation associated with the growth of feedstocks. However, these emissions are often captured elsewhere in fuel carbon pathways and tend to be highly specific to each project. In addition, none of the processing emissions associated with fuels production are included, as there is a myriad of ways to produce fuels from biogas; in this way the emissions reduction potential is a **gross** value of emissions reduction potential, not net. Still, manure and biowaste projects net carbon intensity will normally be negative when feedstock acquisition avoided emissions are included. The analysis offers gross totals of emissions reduced by deployment of anaerobic digestion and the use of the various feedstocks, as those actions are themselves largely responsible for the associated benefits.



¹¹ https://edgar.jrc.ec.europa.eu/dataset_ghg2024#p1

¹² (FAOSTAT, 2023, GCE dataset)

¹³ (FAOSTAT, 2023, GLE dataset)

Several references and databases for emissions estimates were considered,^{14,15,16,17} however, the EDGAR database was found to be the most consistent and detailed by both country and emissions type for biowaste, and the FAO databases of crop and manure emissions is also very detailed and is frequently referenced in other studies of the subject.

IEA nation groupings titled “Rest of Asia Pacific”, “Other Emerging and Developing Economies” and “Other Advanced Economies” were grouped together in one category in this analysis: “Rest of World”. “Rest of Europe” and “European Union” were grouped into “Europe”, except for Biowaste. Mexico (pg. 50 of IEA) was included with Central and South America. Alignment between IEA’s nation groupings and those used for compiling GHG data herein has not been checked against IEA’s source data groupings (not available to author), but this should not affect the broader conclusions. The IEA’s biomethane estimate for biowaste excluded volumes of materials already going to incineration and composting, and in the EU this would be significant. Therefore, for the EU energy/fossil CO₂ emissions estimate from biowaste, the biomethane potential of currently composted or incinerated biowaste fractions was added *back* into the potential gas yield.

Results Summary Table and Geochart in Millions of Tons CO₂e on following pages.

Analysis Fossil Energy and CO₂ displacement:
Biomethane from available non-food, non-feed, non-woody feedstocks is estimated at 32.2 EJ worldwide. Agricultural residue is the largest source of energy feedstock, followed by manure, followed by biowaste. In comparison with worldwide fuel use for shipping today at 11EJ¹⁸, sufficient resources are available to cover maritime needs, even when accounting for conversion losses through liquefaction or bio-methanol synthesis. When displacing fossil gas, biogenic short-cycle biomethane offers to eliminate 1.82GTe annually, not accounting for processing conversion energy consumption. This is against fossil gas CO₂ emissions and does not credit the initial conversion from oil to fossil gas (i.e. reference of 56.1g/MJ CO₂e). To realize the fossil CO₂ displacement potential of biomethane, system leaks and losses must be avoided to the greatest possible extent. The use of biomethane as a fuel requires rigorous leak and slip-by avoidance measures throughout the processing and combustion stages. Excluding any avoided methane credits or processing penalties (i.e. RNG CI of 0g/MJ CO₂e), an overall system leakage rate of 7.5% and 3% would void all GHG benefits vs. fossil gas at GWP-100 and GWP-20, respectively.¹⁹

BAU Feedstock Methane:

The avoided emissions potential of global manure, biowaste and crop residue feedstocks via the AD pathway is at least as large as the associated displacement of fossil gas with biomethane. The potential for reducing fugitive methane from the waste management sector ALONE is as valuable as the total world energy potential of biomethane (1818 MM tons vs 1787 MMtons). And this is considering the 100-year GWP, not the 20-year GWP, which would be 3.5x greater. Waste management in developing and emerging economies represents a large and rapidly growing climate liability, while capital deployment in this sector is sorely lacking due to insufficient secured revenue. Mitigating fugitive methane emissions via the diversion of wastes to digestion (away from landfill) is crucial to addressing a massive, rising and uncontrolled source of global GHGs. Current practice in recognition of avoided emissions from the waste sector is inconsistent and generally not fully

¹⁴ (International Energy Agency (IEA) 2025)

¹⁵ (Saunois et al, 2020)

¹⁶ (EDGAR, 2024)

¹⁷ (FAOSTAT, 2023)

¹⁸ (International Energy Agency, World Energy Outlook, 2024)

¹⁹ (Grubert, 2020)

credited²⁰ – this must be remedied in future low-carbon fuel schema. Properly crediting and managing avoided methane from all AD pathways can yield large results quickly through proven fuel pathways.

BAU Feedstock Nitrous Oxide:

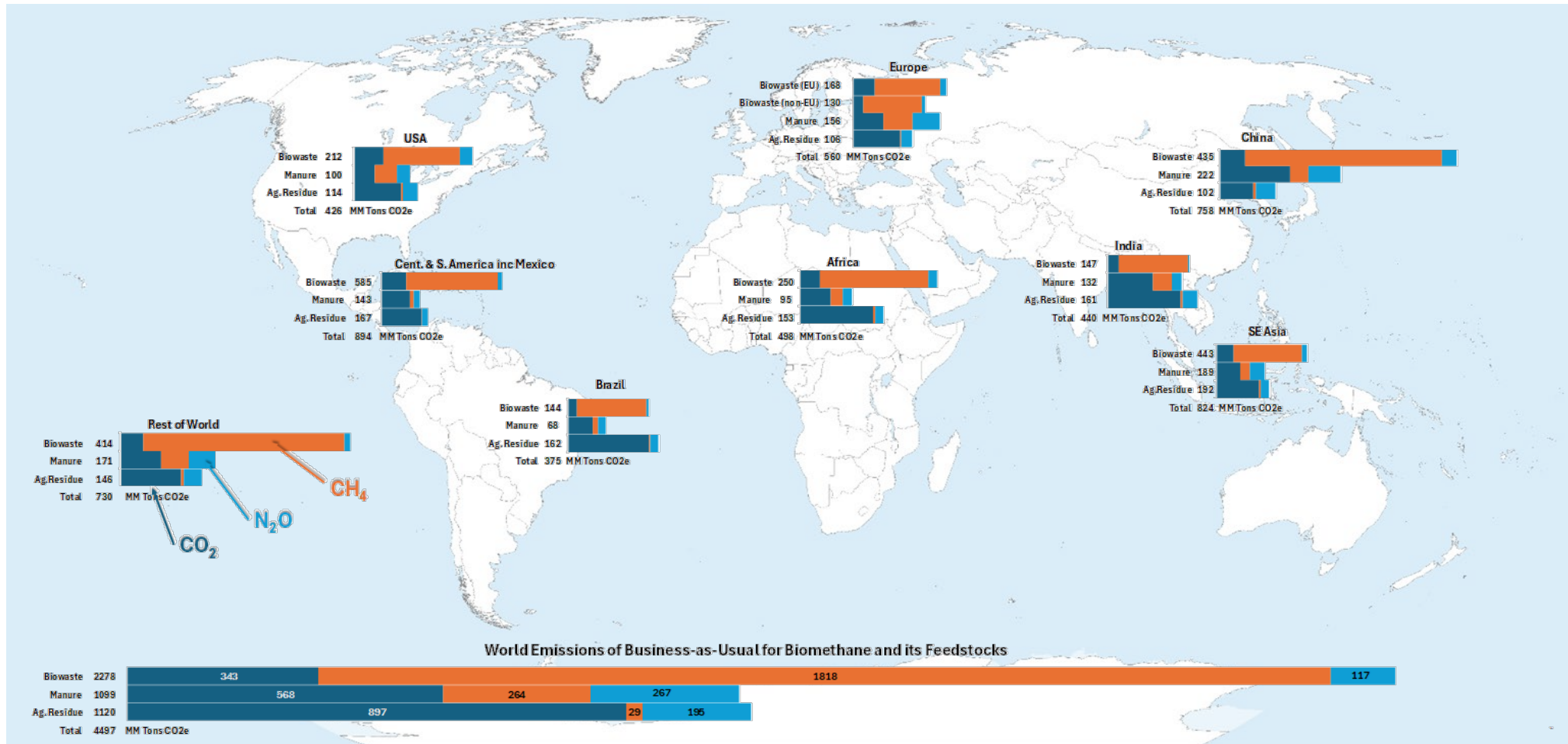
For manure management, the avoided emissions potential from N₂O is as large as the avoided fugitive CH₄ potential. Anaerobic digestion with appropriate storage of digestate will largely avoid the direct N₂O associated with manure management and storage. However, the N₂O generated by leaving crops in the field or land applying raw manure is not automatically reduced by digestion when digestates are returned to the fields. In some cases, N₂O emissions are stimulated and much depends on the interaction between digestate quality and soil conditions.²¹ Therefore, it is critical to credit, track and compensate the nitrogen aspect of digestate management and crop waste use. In practice, it would be appropriate to estimate 90% of N₂O emissions from manure collection and storage and around 30-50% of those associated with leaving crop waste on the field and land applying raw manure can be mitigated by anaerobic digestion.

²⁰ (Bioenergy Association of New Zealand, 2024)

²¹ (Abalos et al. 2022)

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China		Energy (EJ)	Fossil CO ₂	Fugitive CH ₄	Fugitive N ₂ O	Gross CO ₂ e
	Biowaste	0.8	46	361	28	435
	Manure	2.3	129	33	59	222
	Ag. Residue	1.1	61	5	36	102
	Totals	4.2	236	400	122	758

Rest of World		Energy (EJ)	Fossil CO ₂	Fugitive CH ₄	Fugitive N ₂ O	Gross CO ₂ e
	Biowaste	0.7	40	362	11	414
	Manure	1.3	73	50	48	171
	Ag. Residue	1.9	109	4	33	146
	Totals	4.0	222	416	92	730

Africa		Energy (EJ)	Fossil CO ₂	Fugitive CH ₄	Fugitive N ₂ O	Gross CO ₂ e
	Biowaste	0.6	36	198	16	250
	Manure	1.0	57	21	17	95
	Ag. Residue	2.4	133	4	15	153
	Totals	4.0	226	223	49	498

India		Energy (EJ)	Fossil CO ₂	Fugitive CH ₄	Fugitive N ₂ O	Gross CO ₂ e
	Biowaste	0.4	20	125	2	147
	Manure	1.4	81	34	18	132
	Ag. Residue	2.3	131	4	26	161
	Totals	4.1	232	163	45	440

USA		Energy (EJ)	Fossil CO ₂	Fugitive CH ₄	Fugitive N ₂ O	Gross CO ₂ e
	Biowaste	0.9	53	137	23	212
	Manure	0.6	36	40	23	100
	Ag. Residue	1.5	85	3	26	114
	Totals	3.1	174	180	72	426

Europe		Energy (EJ)	Fossil CO ₂	Fugitive CH ₄	Fugitive N ₂ O	Gross CO ₂ e
	Biowaste (EU)	0.7	38	119	11	168
	Biowaste (non-EU)	0.3	18	106	6	130
	Manure	1.0	55	53	49	156
	Ag. Residue	1.5	85	2	19	106
	Totals	2.8	158	160	74	392

Brazil		Energy (EJ)	Fossil CO ₂	Fugitive CH ₄	Fugitive N ₂ O	Gross CO ₂ e
	Biowaste	0.3	16	125	4	144
	Manure	0.8	44	9	14	68
	Ag. Residue	2.6	145	2	15	162
	Totals	3.7	206	136	32	375

Cent & S.Am. Inc. Mex		Energy (EJ)	Fossil CO ₂	Fugitive CH ₄	Fugitive N ₂ O	Gross CO ₂ e
	Biowaste	0.8	44	162	8	215
	Manure	0.9	50	7	11	68
	Ag. Residue	1.3	71	1	10	83
	Totals	3.0	166	171	30	366

Southeast Asia		Energy (EJ)	Fossil CO ₂	Fugitive CH ₄	Fugitive N ₂ O	Gross CO ₂ e
	Biowaste	0.5	30	124	9	163
	Manure	0.8	42	17	27	87
	Ag. Residue	1.4	77	3	15	94
	Totals	2.7	149	144	51	344

Whole World		Energy (EJ)	Fossil CO ₂	Fugitive CH ₄	Fugitive N ₂ O	Gross CO ₂ e
	Biowaste	6.1	343	1818	117	2278
	Manure	10.1	568	264	267	1099
	Ag. Residue	16.0	897	29	195	1120
	Totals	32.2	1808	2111	578	4497

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Country Groups:

Cent& S.Am. inc. Mex Anguilla Antigua and Barbuda Argentina Aruba Bahamas Barbados Belize Bermuda Bolivarian Republic of Venezuela (Venezuela) Bonaire British Virgin Islands Cayman Islands Chile Colombia Costa Rica Cuba Curaçao Dominica Dominican Republic Ecuador El Salvador Falkland Islands (Malvinas) Grenada Guatemala Guyana Haiti Honduras Jamaica Montserrat Nicaragua Panama Paraguay Peru Plurinational State of Bolivia (Bolivia) Saint Kitts and Nevis Saint Lucia Saint Pierre and Miquelon Saint Vincent and the Grenadines Sint Eustatius and Saba Sint Maarten (Dutch part) Suriname Trinidad and Tobago Turks and Caicos Islands. Uruguay	Europe (non-EU) Albania Belarus Bosnia and Herzegovina Ireland Israel Macedonia, the former Yugoslav Republic of Norway Switzerland Turkey Ukraine United Kingdom	Africa Angola Burundi Benin Burkina Faso Botswana Central African Republic Cote d'Ivoire Cameroon Congo, the Democratic Republic of the Congo Comoros Cape Verde Djibouti Algeria Egypt Eritrea Western Sahara Ethiopia Gabon Ghana Guinea Gambia Guinea-Bissau Equatorial Guinea Kenya Liberia Libyan Arab Jamahiriya Lesotho Morocco Madagascar Mali Mozambique Mauritania Mauritius Malawi Namibia Namibia Niger Nigeria Reunion Rwanda Sudan Senegal Saint Helena Sierra Leone Somalia Sao Tome and Principe Swaziland Seychelles Chad Togo Tunisia Tanzania, United Republic of Uganda South Africa South Africa Zambia Zimbabwe	RoW Afghanistan United Arab Emirates Armenia Australia Azerbaijan Bangladesh Bahrain Bhutan Canada Cook Islands Fiji Georgia Iran, Islamic Republic of Iraq Jordan Japan Kazakhstan Kiribati Korea, Republic of Kuwait Lebanon Sri Lanka Macao Maldives Mongolia New Caledonia Nepal New Zealand Oman Pakistan Palau Korea, Democratic People's Republic of French Polynesia Qatar Russian Federation Saudi Arabia Solomon Islands Syrian Arab Republic Tajikistan Turkmenistan Tonga Taiwan, Province of China Uzbekistan Vanuatu Samoa Yemen
Southeast Asia Brunei Darussalam Cambodia Indonesia Lao People's Democratic Republic Malaysia Myanmar Philippines Singapore Thailand Viet Nam	Europe (EU) Austria Belgium Bulgaria Cyprus Czech Republic Germany Denmark Spain Estonia Finland France Greece Croatia Hungary Ireland Italy Lithuania Luxembourg Latvia Malta Netherlands Poland Portugal Romania Slovakia Slovenia Sweden		

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